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Analytical Prescription Models of Lightweight Concrete Mixtures With (Leca) Expanded Clay Aggregate

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Abstract:

Lightweight aggregate concrete is a novelty in the construction industry, and it attracts a lot of attention. In this manuscript, the three batches of lightweight concrete mixtures (LC 16/18, LC 18/20, and LC 20/22) were designed. The highlighted section was based on the calculation pattern of these lightweight concrete mixtures' prescription models. The scrutiny on the trial lightweight concrete mixtures was conducted at Joint Research Centre in Ispra, Italy. The overall significance lies in composing the trial lightweight concrete mixtures with satisfying features based on this calculation pattern. Besides this, it was demonstrated that it is utterly feasible to follow the guidelines for a lightweight-concrete mix design and set a predetermined volume density following a future concrete purpose.

Keywords: *lightweight concrete mixtures, calculation pattern, prescription models, guidelines, the future purpose of concrete*

I. INTRODUCTION

Lightweight can be classified as lightweight aggregate concrete, foamed concrete, and autoclaved, aerated concrete [1]. The lightweight aggregate concrete (LWAC) exploitation was rooted back in 3000 BC. In Europe, the first utilization mould of LWAC was noted around two thousand years ago, when the Romans built glorious objects such as Pantheon and Colosseum [2]. With the densities ranging from 50 kg/m³ to 1000 kg /m³ for lightweight aggregates, it is feasible to compose super small weight LWAC of extra high compressive strengths. The LWAC is tailored with different binders (limestone, mortar, cement, gypsum), aggregates which can be natural originated (pumice, scoria, tuff, palm oil shell, clay, sand, gravel) or human-made (synthetic resins, polystyrene beads) and water.

Many supplementary, cementitious and recycled admixtures were utilized as coarse aggregates in lightweight concretes.

Reference [3] reports about structural lightweight aggregate concrete, composed with basaltic pumice, scoria as aggregate and fly ash as mineral admixture, in a 20 % replacement of the Portland cement's weight. The lightweight concrete impregnated with oil palm shell as solid waste, coarse aggregate and the high volume of type F fly ash combined with Portland cement, was investigated in [4].

The reinforcement of lightweight aggregate concrete with polypropylene and steel fibres was investigated [5]. The steel fibres increased the ductility of lightweight aggregate concrete but did not influence the value of compressive strength. Neither the polypropylene fibres influenced on the compressive strength of lightweight aggregate concrete. A scrutiny carried out on the usage of lightweight aggregate concrete in marine domains, proved that lightweight aggregate concrete could withstand the rigorous conditions in marine and offshore environment, endures the erosions and abrasions of surfaces exquisitely.

In this manuscript, the pre-experimental and counting recipes for three lightweight series of concretes (LC16/18, LC18/20 and LC 20/22) were designed. The key role played the calculation pattern, which was utilized for these trial lightweight concrete mixes. It was demonstrated that it is utterly feasible to follow the guidelines for a lightweight-concrete mix design and set a predetermined volume density in accordance with the future purpose of a concrete.

II. THE PRODUCTION AND UTILIZATION PATTERNS OF LECA EXPANDED CLAY AGGREGATE

The utilized lightweight aggregate in mentioned, composed lightweight concrete mixes, is lightweight expanded clay aggregate which originates from Laterite, Milan, Italy. Laterite is an Italian company whose history began in 1964, and its manufacturing range comprises: lightweight, granular materials, special concretes such as (one-grain, cavernous concrete, cellular concrete, foamed concrete), sorts of screeds and mortars and a wide assortment of thermal insulation blocks. LECA expanded clay aggregate is a non-combustible product which has a foam or a sponge-like internal pore configuration fenced with a sturdy, clinkered", outer shell. This aggregate has so-called "open porosity" with conspicuous inner voids.

Previous paperwork findings showed that the specific gravity of LECA expanded clay aggregate is 16-46 % less than the specific gravity of normal weight aggregates. Also, incorporation of LECA expanded clay as lightweight aggregate in structural lightweight concretes is at a desirable extent present [6]. Comparing the specimens of lightweight concrete, one with plastic waste aggregate (recycled polyethene) and another with pre-wetted expanded clay aggregate, the latter showed better cement hydration process and two times lower water absorption [7]. The previously executed researches indicated the mean-scale strengths (compressive and flexural) of LECA concrete [7].

Light expanded clay aggregate (LECA) has been manufactured and utilized with different denominations in many countries over the world: Italy, Switzerland, Germany, Sweden, United Kingdom, China [8]. This lightweight aggregate has been used in greenhouse and greenroof cultivation, as finishing material and levelling of screeds, as a backfill of walls, acoustic and thermal insulation and in water drainage systems for some filtration layers [9].

Fig 1: LECA Laterlite expanded clay in a granular form before sieving

Fig 2:LECA Laterlite expanded clay in plastic containers.

III. GRANULOMETRY AND GRANULOMETRIC COMPOSITION OF EXPANDED CLAY AGGREGATE

The specifications of concrete designs can be interpreted either by prescription of a concrete mix or by performance requirements (desired workability, slump value, consistency, modulus of elasticity, water-cement ratio, durability). Such specifications may be absolute limits, (strength) class limit characteristic values or target values [10].

The granular composition of inclusive aggregates in a concrete mix design is, in fact, the familiarity with the grain size of aggregates placed in the concrete mix. Since the distribution of a certain grains' sizes is completely arbitrary in the aggregate, the determination of aggregate granulometric composition is executed towards fractions. The percentage share of certain grain groups (fractions) in a total mass of aggregate is defined as granulometric composition, and technical discipline which tackles with the granulometric composition of materials is granulometry. For the determination of aggregate's granulometric composition generally are implemented two standard procedures: sieving method and deposition method (sedimentation).

Theoretically, the permitted quantity of grains, with an upper size (above) a fraction size is 10 % and permitted quantity of grains with a smaller size, (below) a fraction size is 15 % [11].

In this manuscript, the two fractions of LECA, Laterite expanded clay, 2-3 mm and 3-8 mm fractions were sieved to retain the maximum fraction of 6.3-10 mm of the aggregate. All practical sieving measurements and calculations of prescription models for lightweight concrete mixtures were made in ELSA, European Laboratory for Structural Assessment, at the Joint Research Centre located in Ispra, Italy.

On ***Fig 3*** is given the used laboratory kit of sieves with openings' diameters d_i=20 mm, 16 mm, 12.5 mm, 10 mm, 6.3 mm, 4 mm, 2 mm, 1 mm.

Fig 3: The metallic laboratory kit of sieves in ELSA laboratory

Further, are attached the granulometric compositions and curves for 2-3 mm and 3-8 mm fractions of (LECA)Laterlite expanded clay aggregate. Table 1 displays the values for the granulometric composition of 3-8 mm fraction of expanded clay aggregate. The corresponding granulometric curve for 3-8 mm fraction of expanded clay aggregate is shown in ***Fig 4***.

TABLE I

Granulometric composition for a fraction (3-8 mm) of expanded clay aggregate

Table for the fraction 1 (3-8) expanded clay A/ I				
d_i (mm)	a_i (g)	O_i (g)	P_i (%)	Y_i (%)
20	0 g	0 g	0	100 %
16	0 g	0 g	0	100 %
12.5	0 g	0 g	0	100 %
10	27.57 g	27.57 g	0.34 %	99.66 %
6.3	3695.47 g	3723.04 g	46.1 %	53.9 %
4	4208.24 g	7931.28 g	98.186 %	1.814 %
2	144.61 g	8075.89 g	99.977 %	0.023 %
1	1.87 g	8077.76 g	100 %	0 %
0	0 g	8077.76 g	100 %	0 %

a_i- measured mass of the residue on the certain sieve;

The o_i-cumulative residue of the sieve with opening's diameter d_i, which is equal to the sum of all partial residues on the sieves above it;

$$Oi = \Sigma ai$$

pi- percentage size of the residue relative to the overall mass of the aggregate;

$$p_i = \frac{\text{Oi}}{\text{A}}\, x\, 100\ (\%)$$

Yi- a percentage of passing through a certain sieve with opening's diameter.

$$Y_i = 100 - p_i(\%) = \left(1 - \frac{O_i}{A}\right) x\ 100\ (\%)$$
$$= \left(1 - \frac{1}{A}\sum a_i\right) x\ 100\ (\%)$$

All tabular values are calculated according to the predefined general formulations for the granulometric composition of aggregate. The total mass of sieved aggregate can be calculated as cumulative residue on the bottom of the sieves' kit.

The total mass of sieved 3-8 mm fraction of LECA Laterlite expanded clay corresponds to the mass of 8077.76 g.

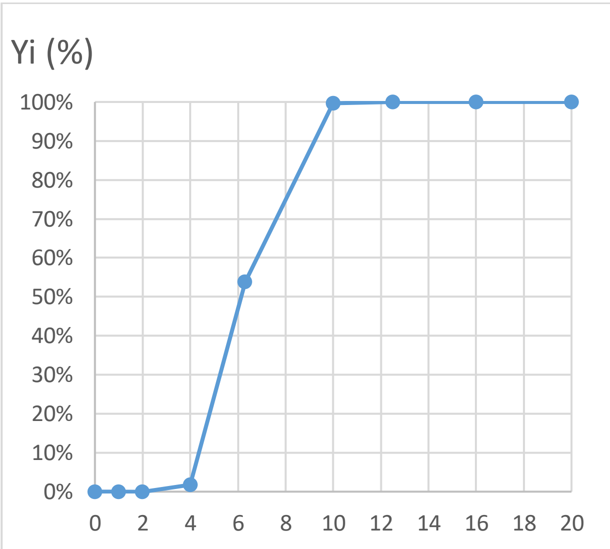

Fig 4: Graphic of a granulometric curve for a 3-8 mm fraction of expanded clay aggregate

In **TABLE II** and ***Fig 5*** are attached to the granulometric composition, and granulometric curve for a 2-3 mm fraction of LECA Laterlite expanded clay aggregate.

TABLE II

Granulometric composition for a fraction (2-3 mm) of expanded clay aggregate

Table for the fraction 2 (2-3) expanded clay A/ II				
d_i (mm)	a_i (g)	O_i (g)	P_i (%)	Y_i (%)
20	0 g	0 g	0	100 %
16	0 g	0 g	0	100 %
12.5	0 g	0 g	0	100 %
10	0 g	0 g	0	100 %
6.3	4.37 g	4.37 g	0.04 %	99.96 %
4	4090.17 g	4094.54 g	37.624 %	62.376 %
2	6548.06 g	10 642.6 g	97.794 %	2.206 %
1	240.06 g	10 882.66 g	100 %	0 %
0	0 g	10 882.66 g	100 %	0 %

The total mass of sieved 2-3 mm fraction of LECA Laterlite expanded clay corresponds to the mass of 10 882.66 g.

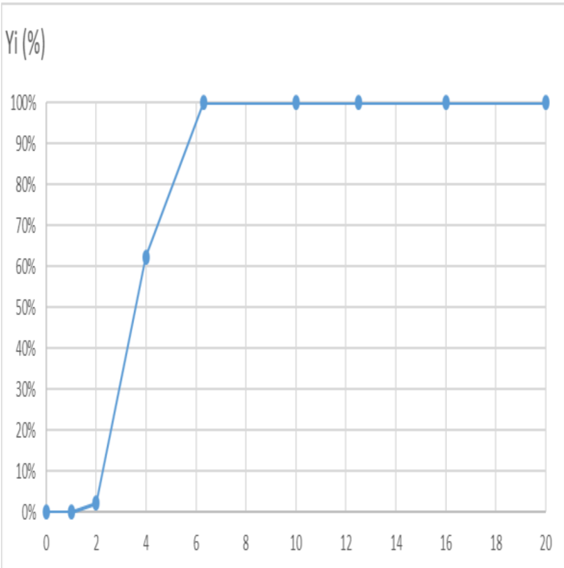

Fig 5:Graphic of a granulometric curve for 2-3 mm fraction of expanded clay aggregate

As a filler and supplement of (LECA), Laterite expanded clay, was taken the fraction of petty sand with the grain size 0-2 mm. These grain sizes and types, of 1 mm and 2 mm, were sieved several times to level out the value of standard deviation, to be smaller than 5 %. Likewise, for the cement type was chosen CEM II/A-LL 42.5 R, Portland-limestone cement, with up to 20 % of limestone by cement mass. The designation 42.5 R signifies the cement class with high early strength at either 2 days or 7 days, following the European standard EN 196-1.

Additives for these 3 batches of lightweight aggregate concrete (LC 16/18, LC 18/20, LC 20/22) were mainly superplasticizers. The aim of making such lightweight concrete mixtures was their further utilization as thermal insulation boards.

IV. PRESCRIPTION MODELS OF LIGHTWEIGHT CONCRETE MIXTURES WITH (LECA) EXPANDED CLAY AGGREGATE

The guidelines for a lightweight-concrete mix design were oriented towards definite and proposed quantities of lightweight concrete's constituents. The three designed batches of lightweight concrete mixes (LC 16/18, LC 18/20 and LC 20/22) were intended for non-structural purposes, namely thermal insulation purposes, thus they did not have high compressive strengths (20-25 MPa).In the label for the lightweight concrete, the first number determines the compressive strength of a cylinder and the second number compressive strength of a cube. Their volume density was predefined, in an amount of 1200 kg/m³. The mutual water-cement ratio for all three lightweight concrete batches was taken as 0.5, to maximize the quantity of used LWA in the concrete mix and reduce the use of cement. With the reduced use of cement in the concrete mix, the carbon footprint is diminished.

Initial assumptions that were taken for the calculation pattern of lightweight concrete mix LC 16/18 are [12]:

1. W/C= 0.5;
2. The total percentage of aggregate was taken as 80 % of the concrete mix;
3. The percentage of pores in the concrete mix was $\upsilon p \sim 3\% = 0.03$;
4. The additive superplasticizer DYNAMON SP1 MAPEI was used with a specific density $\gamma_{ad1} = 1100$ kg/m³;
5. The specific density of cement was taken as 3000 kg/m³ and a specific density of a water 1000 kg/m³.

Calculation pattern for the concrete mix LC 16/18 was the following:

$$\frac{m_a}{\gamma_{sa}} + \frac{m_c}{\gamma_{sc}} + \frac{m_v}{\gamma_{sv}} + \frac{m_{ad1}}{\gamma_{ad1}} + \nu_p = 1$$

- equation for the design of concrete mix composition with absolute volumes of constituent materials ....(1)

$m_{ad1} = 1\% \text{ x } m_c = 0.01m_c$ ....(2)

$0.8 + \frac{m_c}{3000} + \frac{0.5\ m_c}{1000} + \frac{0.01m_c}{1100} + 0.03 = 1$ ....

$0.8 + 0.00033\ m_c + 0.0005m_c + 0.00000909\ m_c + 0.03 = 1$...

$0.00084\ m_c = 0.17$ ....

$m_c = 202.381 \text{ kg}$..

$$m_v = 0.5 \text{ x } m_c = 101.191 \text{ kg}$$

$$m_{ad1} = 0.01 \text{ x } m_c = 2.024 \text{ kg}$$

$1200 = m_a + m_c + m_v + m_{ad1}$ ....(3)

$$m_a = 894.404 \text{ kg}$$

0-2 mm-sand

2-20 mm- expanded clay aggregate

By using the following Fuller curve coefficients in a percentage, the masses of constituent materials in a concrete mix were calculated.

$$m(0-1) = 22.36\ \% \text{ x } m_a = 199.99 \text{ kg}$$

$$m(1-2) = (31.62 - 22.36)\% \text{ x } m_a = 82.82 \text{ kg}$$

$$m(\text{sand}) = m\ (0-1) + m\ (1-2) = 282.81 \text{ kg}$$

$$m(2-3) = (38.73 - 31.62)\% \text{ x } m_a = 63.6 \text{ kg}$$

$$m(3-4) = (44.72 - 38.73)\% \text{ x } m_a = 53.575 \text{ kg}$$

$$m(4-6.3) = (56.125 - 44.72)\% \text{ x } m_a = 102 \text{ kg}$$

$$m(6.3-8) = (63.245 - 56.125)\% \text{ x } m_a = 63.682 \text{ kg}$$

$$m(8-10) = (70.71 - 63.245)\% \text{ x } m_a = 66.767 \text{ kg}$$

$$m(10-12.5) = (79.057 - 70.71)\% \text{ x } m_a = 74.65 \text{ kg}$$

$$m(12.5-16) = (89.44 - 79.057)\% \text{ x } m_a = 92.866 \text{ kg}$$

$$m(16-20) = (100 - 89.44)\% \text{ x } m_a = 94.45 \text{ kg}$$

$m(0-2) = 282.81 \text{ kg}$ – the mass of sand fraction

$m(2-3) = 63.6 \text{ kg}$ – the mass of 2-3 mm fraction of LECA, Laterite expanded clay aggregate

$m(3-8) = 219.257 \text{ kg}$– the mass of 3-8 mm fraction of LECA, Laterite expanded clay aggregate

$m(8-20) = 328.733 \text{ kg}$ –the mass of 8-20 mm fraction of LECA, Laterite expanded clay aggregate

The total sum of these mass fractions corresponds to the total sum of 894.404 kg of aggregate in a concrete mix LC 16/18.

In the figuration and calculation patterns of other two lightweight concrete mixes (LC 18/20 and LC 20/22) figure the identical percentages of aggregates pores with slight variations in the type and quantity of additives. These concrete mixes have two types of additives.

By analogy to this calculation pattern, in scriptum, prescriptions for the three lightweight concrete mixes (LC 16/18, LC 18/20 and LC 20/22) look in the following way:

V. CONCLUSIONS

It was proved that all three lightweight concrete mixes (LC 16/18, LC 18/20 and LC 20/22) with (LECA), Laterite expanded clay aggregate are well-composed trial mixes.

Likewise, the equation for the design of concrete mix composition with absolute volumes of constituent materials showed valid even for real lightweight concrete mixes. All three lightweight trial concrete mixes had good workability while setting in moulds and long-term volume stability of concrete.

LC 16/18	LC 18/20	LC 20/22
flck, cube =18 MPa, Rck=18 MPa	flck, cube =20 MPa, Rck=20 MPa	flck, cube =22 MPa, Rck=22 MPa
Dnom=20 mm	Dnom=20 mm	Dnom=20 mm
Dmax=(25-32 mm)	Dmax=(25-32 mm)	Dmax=(25-32 mm)
W/C= 0.5	W/C=0.5	W/C= 0.5
water (lit/m^3)- 101.191	water (lit/m^3)-100.77	water (lit/m^3)-101.191
cement (kg/m^3)- 202.381	cement (kg/m^3)-201.54	cement (kg/m^3)-202.381
expanded clay aggr. (kg/m^3)- 611.594	cement-CEM II/A-LL 42.5 R	cement-CEM II/A-LL 42.5 R
sand (kg/m^3), (0-2mm)-282.81	expanded clay aggregate (kg/m^3)-611.909	expanded clay aggregate (kg/m^3)-611.733
superplasticizer (kg/m^3) Dynamon SP1-MAPEI, 1 % mc= 2.024 kg	sand (kg/m^3), (0-2mm)- 282.957	sand (kg/m^3), (0-2mm)-282.874
$\Sigma\gamma$= 1200 kg/m^3	superplasticizer (kg/m^3) Tradimalt, 0.9 % mc= 1.814 kg	superplasticizer(kg/m^3) SIKAViscoCrete1020X-0.5 % mc=1.012 kg
	air-entraining additive (kg/m^3) KEMACON LPA- 0.5 % mc= 1.01 kg	viscosity additive (VMA) (kg/m^3)-0.4 % mc =0.809 kg
	$\Sigma\gamma$= 1200 kg/m^3	$\Sigma\gamma$=1200 kg/m^3

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